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Detailed measurements of charmonium suppression in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with CMS

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Abstract

CMS has measured the nuclear modification factors of prompt J/ψ in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. For prompt J/ψ with relatively high p_T ($6.5 < p_T < 30$ GeV/c), a strong, centrality-dependent suppression is observed in PbPb collisions, compared to the yield in pp collisions scaled by the number of inelastic nucleon-nucleon collisions. During the 2011 data taking period the PbPb collision sample has been increased by a factor of twenty compared to 2010, which allows for more detailed charmonium measurements, e.g. mapping the transverse momentum and centrality dependence of the nuclear modification simultaneously. New results on charmonium suppression based on the full available 2011 data sample will be reported.

1. Introduction

At large energy densities and high temperatures hadronic matter becomes a deconfined and chirally-symmetric system of quarks and gluons, called "Quark-Gluon-Plasma" (QGP). It was also found that this medium produced at RHIC and LHC is strongly-coulpled. One of the strongest signatures of the existence of the QGP is the suppression of quarkonia states, which is thought to be a direct effect of deconfinement when the binding potential between the constituents of a quarkonium state is screened by the colour charges of the surrounding light quarks and gluons. However, there are further possible changes to quarkonium production in heavy-ion collisions. One effect, related to the initial state of the collision, i.e. the modifications of the parton distribution functions inside the nucleus (nuclear shadowing), can reduce the production of quarkonia without the presence of a QGP [1]. A second effect, related to the large number of heavy quarks produced in heavy-ion collisions at Large Hadron Collider (LHC) energies, could lead to an increased production of quarkonia via statistical recombination [2].

The suppression (or enhancement) of J/ψ can be quantified by the ratio of produced J/ψ in AA collisions to those in pp collisions scaled by the number of binary nucleon-nucleon collisions (N_{coll}), known as the nuclear modification factor R_{AA}:

$$R_{\mathrm{AA}} = \frac{\mathcal{L}_{\mathrm{pp}}}{T_{\mathrm{AA}} N_{\mathrm{MB}}} \frac{N_{\mathrm{PbPb}}(J/\psi)}{N_{\mathrm{pp}}(J/\psi)} \cdot \frac{\varepsilon_{\mathrm{pp}}}{\varepsilon_{\mathrm{PbPb}}} \tag{1}$$

[1]A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

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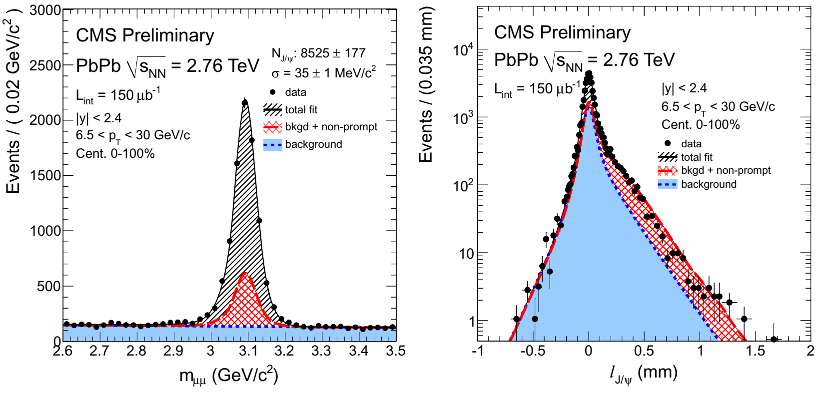

Figure 1: Invariant mass (left) and pseudo-proper decay length (right) distributions of $\mu^+\mu^-$ pairs for $|y| < 2.4$ in minimum bias PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV from CMS [8]. The data (black circles) are overlaid with the projections of the 2-dimensional fit. The different contributions are background (dotted blue line), non-prompt J/ψ (dashed red line), and sum of background, non-prompt and prompt J/ψ (solid black line).

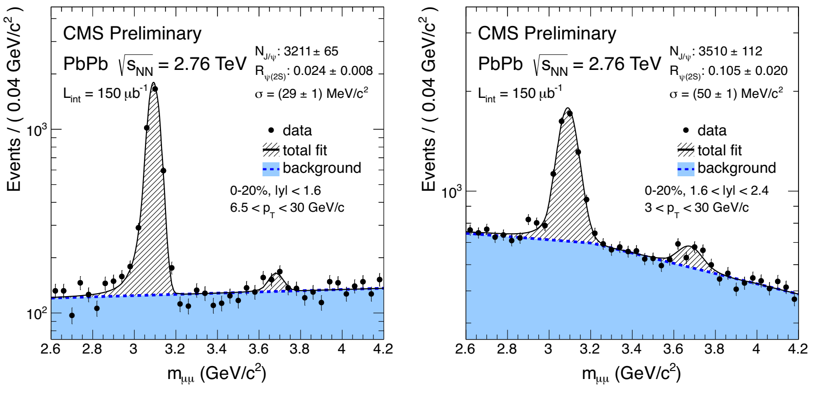

Figure 2: Invariant-mass spectrum of $\mu^+\mu^-$ pairs (black circles) in 0-20% most central PbPb collisions. The p_T and rapidity bins are (left) $6.5 < p_T < 30$ GeV/c and $|y| < 1.6$, (right) $3 < p_T < 30$ GeV/c and $1.6 < |y| < 2.4$. The black line indicates a fit of a CrystalBall plus exponential function to the data [9]. $R_{\psi(2S)}$ is the ratio for the raw yield of J/ψ and $\psi(2S)$.

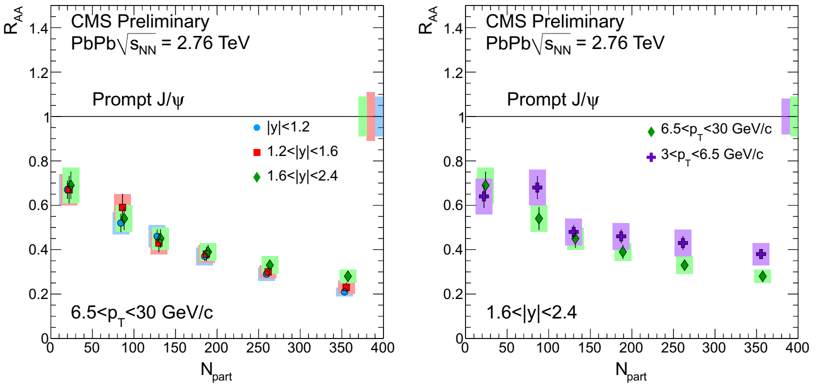

Figure 3: R_{AA} for the high p_T prompt J/ψ, $6.5 < p_T < 30$ GeV/c, for three different rapidity regions (left). R_{AA}, for the forward produced J/ψ, $1.6 < |y| < 2.4$, for two different p_T regions (right). A global uncertainty of 6%, from the integrated luminosity of the pp data sample, is shown as boxes at $R_{AA} = 1$, respectively. Statistical (systematic) uncertainties are shown as bars (boxes) [8].

where $T_{AA} = \langle N_{coll} \rangle / \sigma^{NN}_{inel}$ can be calculated from a Glauber model accounting for the nuclear collision geometry [3]. $\mathcal{L}_{pp}$ is the integrated luminosity of pp collisions and N_{pp} or $N_{PbPb}(J/\psi)$ are the raw yields of J/ψ measured in pp and PbPb collisions. N_{MB} is the count of minimum bias events in PbPb, and $\varepsilon_{pp}/\varepsilon_{PbPb}$ is the multiplicity dependent ratio of the efficiencies in pp and PbPb collisions for trigger and reconstruction, which is determined by a Monte-Carlo simulation based on embedding PYTHIA signal events [4] into HYDJET background events [5]. In the simulation, $\varepsilon_{pp}/\varepsilon_{PbPb}$ was estimated to be about 1.17 for the most central bin. The results are cross checked with real data using a tag-and-probe technique [6].

2. Data samples and analysis procedure

The measurement presented here is based on a $\sqrt{s_{NN}} = 2.76$ TeV PbPb data sample corresponding to an integrated luminosity of 150 μb^{-1}, collected by the CMS experiment in 2011. The pp reference measured at the same nucleon-nucleon collision energy corresponds to an integrated luminosity of 230 μb^{-1}.

The central feature of the CMS apparatus is a superconducting solenoid with a 3.8 T magnetic field. Immersed in the magnetic field are the silicon pixel and strip tracker, the lead-tungstate crystal electromagnetic calorimeter, and the brass/scintillator hadron calorimeter. Muons are measured in gas ionization detectors embedded in the steel return yoke and in the pseudorapidity window $|\eta| < 2.4$ with detection planes made of three technologies: Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers. A more detailed description of the CMS detector can be found in Ref. [7].

CMS classified the measured J/ψ into the prompt component associated with the primary vertex and the non-prompt component associated with a secondary vertex of $\mu^+\mu^-$ pairs [8]. Because B-mesons fly a finite pathlength before they decay, the non-prompt J/ψ can be separated from the prompt ones by the pseudo-proper decay length, $l_{J/\psi} = L_{xy}\frac{m_{J/\psi}}{p_T}$, where L_{xy} is the distance between the primary and the secondary vertices in the transverse plane and $m_{J/\psi}$ is the rest mass of the J/ψ. Figure 1 shows the invariant mass and the projected $l_{J/\psi}$ distributions of $\mu^+\mu^-$ pairs in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [8].

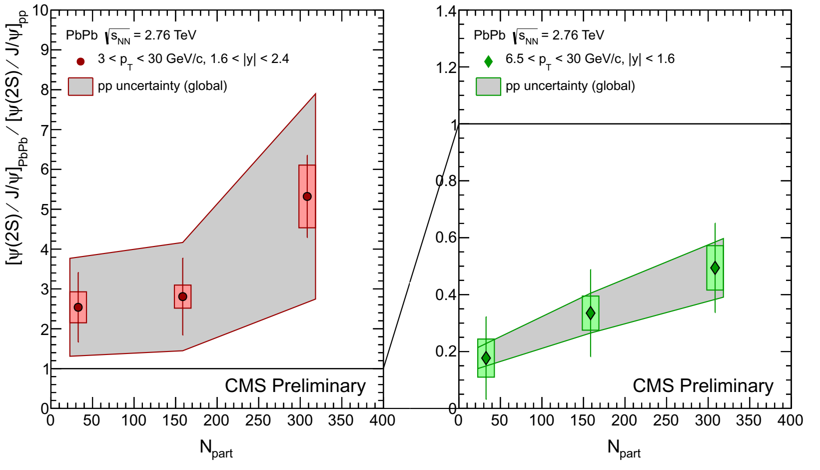

Figure 4: Measured yield double ratio $(N_{\psi(2S)}/N_{J/\psi})_{\rm PbPb}/(N_{\psi(2S)}/N_{J/\psi})_{\rm pp}$ as a function of centrality. The p_T and rapidity bins are $6.5 < p_T < 30$ GeV/c and $|y| < 1.6$ (right) and $3 < p_T < 30$ GeV/c, $1.6 < |y| < 2.4$ (left). The error bars and boxes stand for the PbPb statistical and systematic uncertainties, respectively. The shaded band is the uncertainty on the pp measurement, common to all double-ratio points [9].

3. Results

Figure 3 presents the R_{AA} of prompt J/ψ as a function of the number of participating nucleons ($N_{\rm part}$). A significant centrality dependent suppression of prompt J/ψ production is observed. In the 10% most central events, the suppression reaches a factor of 5 with respect to the pp reference. The suppression decreases towards peripheral events to a factor 1.6 in the 50−100% centrality bin. There is no significant rapidity dependence of the high p_T prompt J/ψ R_{AA} when integrating over centrality and p_T. The low p_T prompt J/ψ are consistent with the suppression of the high p_T prompt J/ψ over all centrality bins.

For the $\psi(2S)$ measurements, the results are presented in the form of the double ratio, $\frac{(N_{\psi(2S)}/N_{J/\psi})_{PbPb}}{(N_{\psi(2S)}/N_{J/\psi})_{pp}}$, shown in figure 4 as a function of $N_{\rm part}$ in both the lower p_T (left) and higher p_T (right) regions. The double ratio measured in $p_T > 6.5$ GeV/c and $|y| < 1.6$ is always less than unity, which means that high-p_T $\psi(2S)$ are more suppressed than J/ψ. However, the data show that the double ratio is larger than unity in the lower p_T range ($3 < p_T < 30$ GeV/c) and at the forward rapidities, although with large statistical uncertainties [9].

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